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**SENSE-ASSESS-AUGMENT:  
A TAXONOMY FOR HUMAN EFFECTIVENESS**

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14. ABSTRACT The Human Effectiveness Directorate at the Air Force Research Laboratory (AFRL) has recently adopted a Sense-Assess-Augment (S-A-A) taxonomy to facilitate the planning, development, execution, and reporting of their human-centered research portfolio. The objective of this taxonomy is to sense individual and team cognitive state, assess the state relative to performance, and augment performance to optimize mission effectiveness. This taxonomy is being applied to revolutionize improvements in human performance by leveraging the integration of several sensing technologies coupled with multiple assessment approaches to provide a robust understanding of the causes of operator performance decrements. Given a better understanding of the causes for sub-optimal performance, targeted augmentation techniques can be employed to improve individual or team performance. The adopted taxonomy has been utilized in the Human Universal Measurement and Assessment Network (HUMAN) laboratory at the Air Force Research Laboratory to examine bottlenecks associated with controlling multiple Remotely Piloted Aircraft (RPAs). This example will be used to illustrate how the S-A-A process was instantiated and utilized to identify and implement targeted augmentations that improve operator performance.					
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## SUMMARY

The Human Effectiveness Directorate at the Air Force Research Laboratory (AFRL) has recently adopted a Sense-Assess-Augment (S-A-A) taxonomy to facilitate the planning, development, execution, and reporting of their human-centered research portfolio. The objective of this taxonomy is to *sense* individual and team cognitive state, *assess* the state relative to performance, and *augment* performance to optimize mission effectiveness. This taxonomy is being applied to revolutionize improvements in human performance by leveraging the integration of several sensing technologies coupled with multiple assessment approaches to provide a robust understanding of the causes of operator performance decrements. Given a better understanding of the causes for sub-optimal performance, targeted augmentation techniques can be employed to improve individual or team performance. The adopted taxonomy has been utilized in the Human Universal Measurement and Assessment Network (HUMAN) laboratory at the Air Force Research Laboratory to examine bottlenecks associated with controlling multiple Remotely Piloted Aircraft (RPAs). This example will be used to illustrate how the S-A-A process was instantiated and utilized to identify and implement targeted augmentations that improve operator performance.

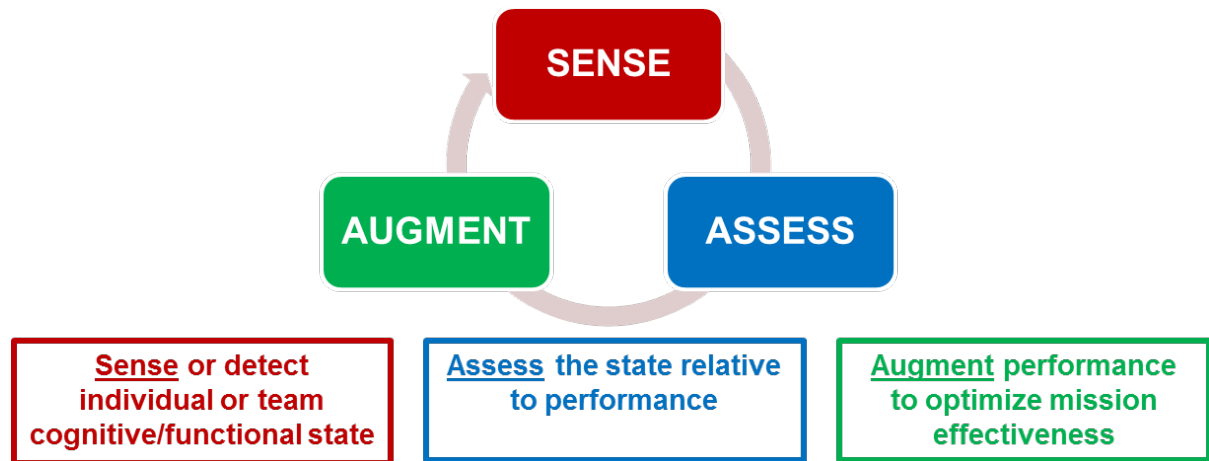
## INTRODUCTION

In 2010, the Chief Scientist of the Air Force released a report outlining the science and technology needs in the 2010-2030 time frame (Dahm, 2010). A key finding from that report was that natural human capacities are becoming increasingly mismatched to the enormous data volumes, processing capabilities, and decision speeds that technologies either offer or demand. Although humans today remain more capable than machines for many tasks, by 2030 it is hypothesized that machine capabilities will be so advanced that humans will become the weakest component in a wide array of systems and processes. Humans and machines will need to become far more integrated, through improved human-machine interfaces, the use of autonomous systems, and by direct augmentation of human performance in order to facilitate the realization of these increased machine capabilities.

Developing ways of using science and technology to augment human performance will become increasingly essential for gaining the benefits that many existing, planned, and future technologies can bring. Significant advances and early implementations are possible over the next decade. Such augmentation techniques are a further means for increasing human efficiencies, facilitating reduced manpower requirements for the same capabilities or even increased capabilities with given manpower.

There are two primary questions one must consider before implementing human performance augmentation: 1) *when* to provide the augmentation and 2) *how* to provide the augmentation. The answers to these questions will ensure the right augmentation technique is employed at the right time to produce the desired effects. Recently, the Human Effectiveness Directorate at the Air Force Research Laboratory has adopted a Sense-Assess-Augment (S-A-A) taxonomy to provide answers to these questions. The objective of this taxonomy is to **sense** individual and team cognitive state, **assess** the state relative to performance, and **augment** performance to optimize mission effectiveness (Figure 1). The Human Effectiveness Directorate is currently applying this taxonomy to conduct research that facilitates improved human performance. Human performance research, therefore, leverages the integration of several sensing technologies coupled with multiple assessment

approaches to provide a robust understanding of the causes of operator or system performance decrements. Given a better understanding of the causes for sub-optimal performance, targeted augmentation techniques can be employed to improve individual or team performance.



**Figure 1. Graphical depiction of the Sense-Assess-Augment (S-A-A) taxonomy**

The S-A-A taxonomy was originally presented during a Human Effectiveness Directorate Scientific Advisory Board review (Galster, 2011). The taxonomy served to facilitate in the planning, development, execution, and reporting of the Applied Neuroscience human-centered research portfolio. In the following year, a workshop was held at Arizona State University where participants from academia, industry, and military sectors convened to examine the S-A-A taxonomy and its utility. The workshop served to validate the taxonomy and included recommendations to continue and expand its use as a common way to describe and report on human-centric research and development efforts. An article describing how the taxonomy could be used across military domains to create the future *quantified warrior* was subsequently published by the Senior Leaders in the Human Effectiveness Directorate (Blackhurst, Gresham, & Stone, 2012).

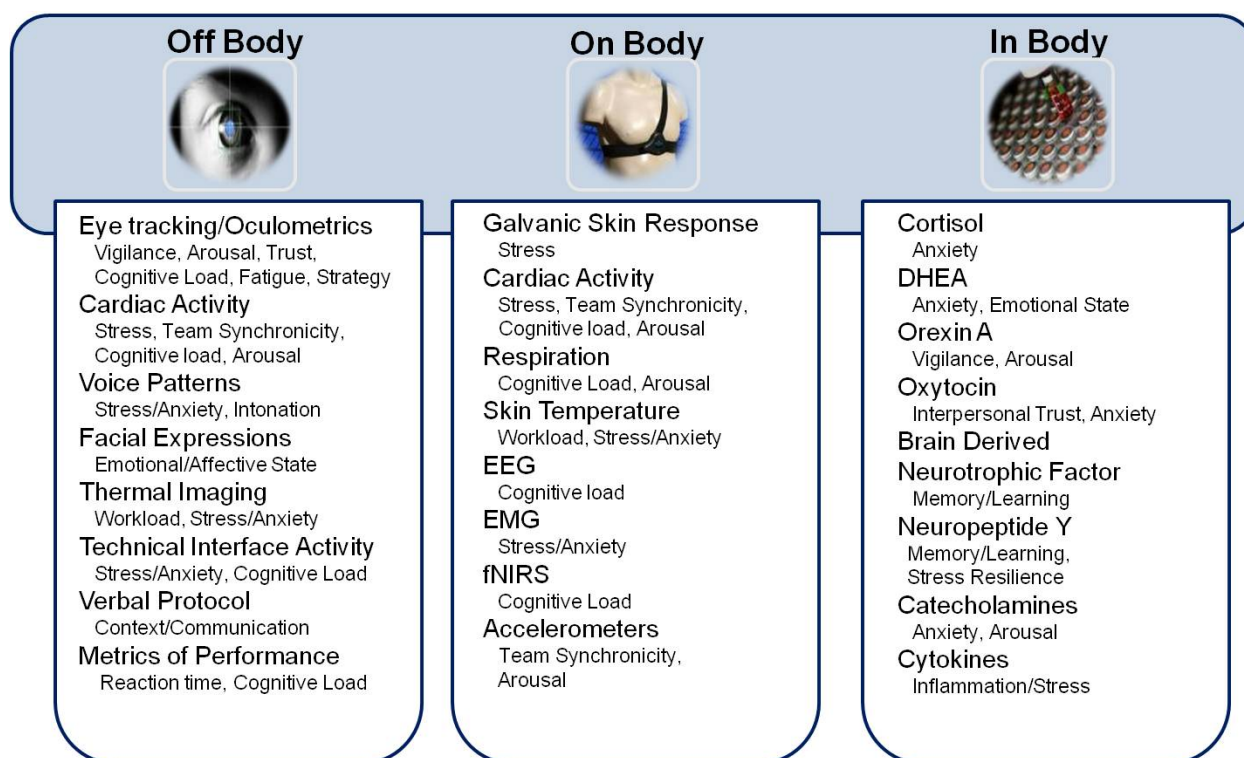
Below, tenets of the S-A-A taxonomy are described followed by an example of how the S-A-A taxonomy is currently being utilized in the Human Universal Measurement and Assessment Network (HUMAN) laboratory at the Air Force Research Laboratory at Wright-Patterson AFB, OH.

## **Sense**

A snapshot of the metrics being used or explored at AFRL to sense cognitive state is depicted in Figure 2. Below each metric is the psychological or behavioral construct of interest typically associated with the use of that particular metric. Recently, a concerted effort has been on integrating several sensing technologies to gather a more robust (reliable and proof of stability over time) “picture” of the operator cognitive state.

Of course, sensors continue to evolve and mature and all efforts must be taken to integrate and test new sensors if feasible. It is also advisable to plan for the rapid integration of new sensing

technologies to the greatest extent possible. One of the primary objectives in the sense portion of the S-A-A taxonomy is to use sensors that are more cost effective, disposable, non- or minimally-invasive and provide measures that are accessible in near real-time.



**Figure 2. Baseline sensing technologies**

## Assess

Assessment techniques can vary widely and are typically chosen by a number of factors; the type of data being collected, the frequency and accessibility of the data produced, the objectives of the evaluation, and expertise of personnel involved to name a few. One major differentiator in deciding what type of assessment technique or approach to utilize is whether a top-down, model driven approach or a bottom-up data driven approach is better suited to a particular application. Some examples of “standard” assessment techniques include the use of nonlinear classification methods such as artificial neural networks, kernel based support vector machines, kernel based discriminant analysis, and the use of manifold learning classifiers (see also, Pereria, Mitchell, & Botvinick, 2009; Christensen, Estep, Wilson, & Russell, 2012). There will always be benefits and risks associated with choosing one approach over another. It will be up to the individual utilizing the assessment method to determine the best approach, again given the particular application. The assessment phase is critical in determining *when* to engage the augmentation. A key component in answering this question is completing the required analysis in near real time so the augmentation, if needed, can be deployed before the degraded operator cognitive state causes irreparable consequences in performance that may result in mission failure.



## Augment

Augmentation approaches span the use of neuropharmaceuticals, biofeedback, physical training, and brain stimulation. Techniques such as biofeedback and brain stimulation were originally developed in clinical domains to treat neurological and psychological deficits, however their potential to enhance cognitive abilities and performance in healthy individuals have recently been explored. These techniques have the potential to improve multiple facets of cognition including memory, alertness, executive function, and visual/aural acuity. More controversial techniques such as implants or even genetic modification are possible augmentation options. While such methods may not be culturally acceptable by some, potential adversaries may be willing to make use of them without reservation. It is important to understand all augmentation possibilities and outcomes. Developing acceptable ways of using science and technology to augment human performance will become increasingly essential for realizing the benefits that many technologies afford. The current technical maturity of various approaches in this area varies widely, but significant steps to advance and develop early implementations are possible now and over the next decade.

## Application

The utilization of the S-A-A taxonomy allows researchers and practitioners to identify specific bottlenecks that may occur during operations. The correct identification of the individual's source for sub-optimal performance will drive what augmentation method should be utilized to provide increases in human performance. There are efforts currently underway to utilize the S-A-A taxonomy to examine the use of contextually relevant augmentation techniques in the control of multiple remotely piloted aircraft (RPAs). One such augmentation is the use of automation to ease the acute stress and cognitive load an operator may experience as mission demands become more taxing and complex.

The integration of automated tools into highly complex systems has created a need to examine the nature of the interaction between humans and the automated tools that they use. The examination of human performance in systems that utilize automation has become widespread. Investigations of human interaction with automation have revealed that automation does not always function in the way intended by designers and, moreover, can produce deleterious performance effects (Bainbridge, 1983; Billings, 1997; Billings & Woods, 1994; Parasuraman & Riley, 1997; Sarter & Woods, 1995; Woods, 1996). Automation can change the nature of the demands on the operator and produce subsequent changes in performance not seen when automation is absent. A review of human performance costs of automation list possible changes in the mental workload for the operator, an increase in the monitoring demands, and a decrease of the monitoring efficiency of the operator as costs contributing to poor performance (Parasuraman & Riley, 1997; Sheridan, 2002). A reduction in skill due to lack of use and a reduction in the situation awareness of the operator have also been identified as potential costs of automation usage. The issues raised above suggest that automated tools should not be used as a panacea; rather it should be instantiated deliberately under specified conditions that warrant its use.

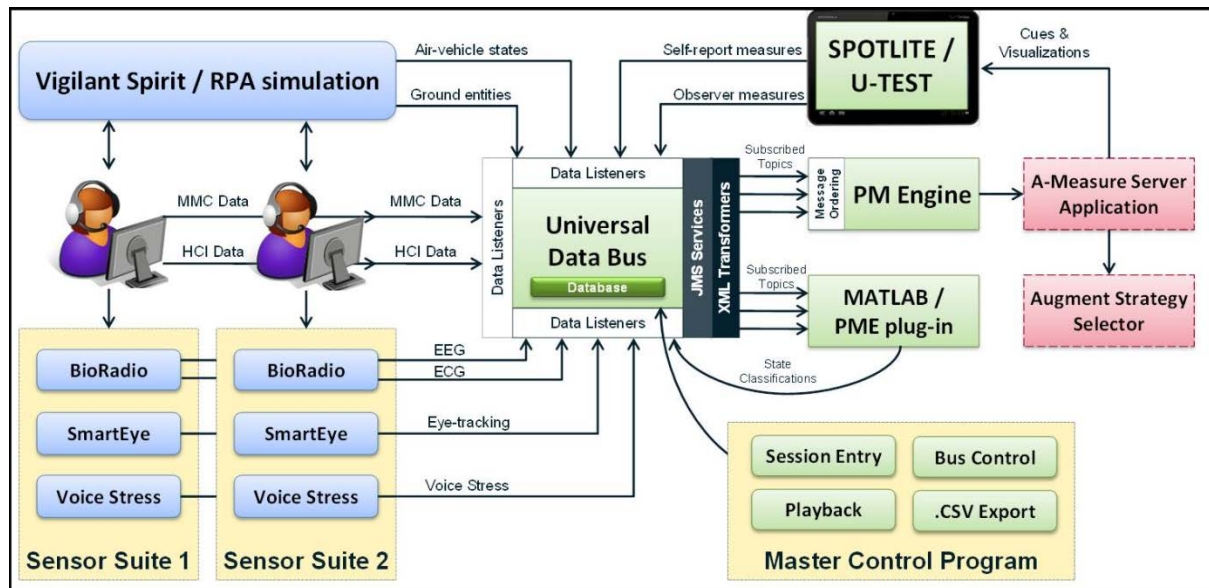
The example that follows is utilizing the S-A-A taxonomy to identify *when* an operator is cognitively loaded, what consequences there are to performance and *what* augmentation technique to employ if a performance decrement occurs that will jeopardize mission assurance. The data is collected and

analyzed along with performance data to compile a comprehensive picture of drivers that may affect operator workload and decision making ability. This understanding provides opportunities to implement performance augmentations or mitigations to alleviate any bottlenecks. The objective of the current effort is to provide design guidance to those who will build the next generation RPA control station. The goal is to step away from a technically-centered design and facilitate a design that is more human-system centric; one that is constantly surveying the operator cognitive state, determining if performance is affected, and able to remediate bottlenecks that may endanger mission performance.

### **The Human Universal Measurement and Assessment Network (HUMAN) Laboratory**

The Human Universal Measurement and Assessment Network Laboratory (HUMAN) Laboratory uses a comprehensive measurement and assessment approach to provide performance optimization and mitigation recommendations that are based on a thorough understanding of the complexities that exist in contextually rich activities. The HUMAN Laboratory is equipped with a state-of-the-art multimodal data acquisition system, including sensors to monitor brain, heart, muscle-activity, eye movement, respiration, galvanic skin response and other body signals. These data and performance data from the RPA simulation environment are fed into a commercially available architecture, translated to an XML-based Human Performance Markup Language (HPML) and forwarded to a machine learning-based model for evaluation (see also Durkee, Geyer, Pappada, Ortiz, & Wiggins, 2013; Durkee, Geyer, Pappada, Ortiz & Galster, 2013). Additional data such as self and observer-based measures can also be funneled into the Universal Data Bus for consideration in the evaluative process (Figure 3).

Data collection is currently underway in the HUMAN laboratory. Initial efforts assured that the integrated sensors were performing as planned, that data was being published to the Universal Data Bus, that the data was available for evaluation from the machine learning-based model, and that an initial composite real-time workload measure was being produced. The next step in this process is to include saliva-based biomarkers (dehydroepiandrosterone, cortisol, immunoglobulin A, and alpha-amylase) in the data collection process. These biomarkers will not currently contribute to the real-time operator cognitive state assessment but they will play a critical role in determining the relationship between changes in biochemistry and real-time assessment of operator cognitive workload and stress. This relationship will help define the strategic plan for future sensor development.



**Figure 3. Representative architecture for data collection in the HUMAN laboratory. From Aptima, Inc.**

## DISCUSSION

The basic tenets of the S-A-A taxonomy were described with an example illustrating how the taxonomy is being applied to support the design of future RPA control stations. The taxonomy is currently utilized in a number of other scientific endeavors including the examination of cyber operations, pilot performance, threat detection, and as a guiding construct to improve existing testing, evaluation, validation, and verification methodologies.

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